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EFFECTS OF INDUSTRIAL WASTES ON STREAM LIFE

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Effects of Industrial Wastes on Stream Life *

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The environmental changes that may be brought about by industrial waste effluents that can be detrimental to aquatic life (Figure 1) to varying degrees are: decrease in dissolved oxygen to harmful levels; increase in turbidity; formation of sludge deposits by settleable solids; increase in chemicals to toxic levels; changes in pH toward extremes in acidity or alkalinity; increases in temperature; tainting of fish flesh; production of nutrients resulting in undesirable aquatic growths; and concentration of radioactive materials in aquatic life.

This paper will deal mostly with four that are perhaps the most subtle, namely: the effects of increased temperature; the effects of particulate matter, as turbidity and settleable solids; the effects of nutrients resulting in undesirable aquatic growths; and the relationship of radioactive wastes to aquatic life.

It is emphasized that the detrimental effects of domestic sewage on aquatic life should never be overlooked on industrial waste surveys if untreated or treated wastes from industries and municipalities are discharged into the same body of water. Also, one should fully recognize the overcoming scouring effects that high water may have had in reducing aquatic populations at periods of high discharge before stream surveys were initiated.

EFFECTS OF INCREASED TEMPERATURE

The pollutional effect of temperature increases on over-all aquatic life associations has long been overlooked or ignored in natural waters.

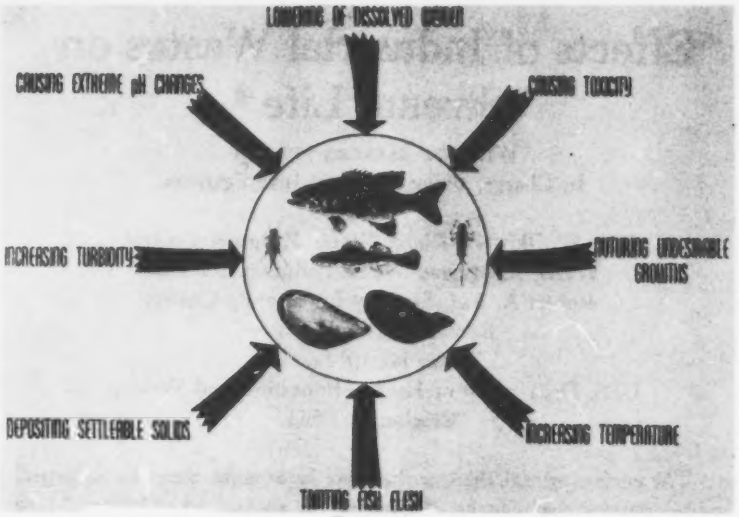

FIGURE 1.

Ways in which industrial wastes may affect aquatic life.

Specifically, however, the subtle yet highly significant effects of temperature increases on the metabolic processes of biota, as such, are reflected in BOD measurements and in formulae calculations concerned with the phenomena of oxidation and reaeration. They have been realized if not fully understood for many years (50). Subtle effects of temperature increases on aquatic life are illustrated by the decrease in solubility of oxygen with temperature increases. For example, the solubility of oxygen in fresh water under a pressure of 760 mm at 0 C is 14.62 ppm, at 20 C it is 9.17 ppm, and at 30 C it is 7.63 ppm. Thus, heat alone, discharged by industries, can deny aquatic life oxygen reserves.

In situations where putrescible waste pollution exists, creating a high BOD and taking from the stream additional oxygen, increased temperatures can become dangerous as they may be related to depletion of dissolved oxygen to asphyxial levels for aquatic life. Another subtle effect of temperature increase is reflected, on occasion, in the increased toxicity of certain chemicals to aquatic forms. For example, it has been shown that raised temperature increases the toxicity of rotenone to fish (18). Brown trout die much more rapidly at 70 F than they do at 55 F, the time being about 15 min at the former temperature and 70 min at the latter with a 0.40 ppm dosage; with dosages of 0.20 ppm they die in about 22 min at 70 F and in 100 min at 55 F. To the

contrary, certain temperature extremes may not be related significantly to toxicity and time of death. Temperatures at 10 C and 25 C have not affected toxicities of ammonia to chubs (59). Further, it has been demonstrated that toxicities of potassium dichromate and naphthenic acid were very similar at 18 C and 30 C.

To obtain extensive data on the effects of temperature increases on fish, one must turn to laboratory research studies where a wealth of data exists, all of which cannot, of course, be summarized or even listed in a survey paper of this nature. Such experimental data have been adequately summarized by a number of persons. Brett, J. R. (1956), "Some Principles in the Thermal Requirements of Fishes," Quarterly Review of Biology, Vol. 31:2, pp. 75-87, is, especially, a very useful and a comprehensive review of this subject. Also see notes (8) and (24). On industrial waste field surveys on large streams it may be difficult to relate detrimental effects of temperature, and heat pollution, to specific aquatic organisms. In bodies of water, such as the Mahoning River in Ohio, where temperatures can become high enough to be lethal to most aquatic organisms in outfall areas, other factors likewise can have their deleterious effects, such as low dissolved oxygen, high turbidities and settleable and floating solids, pH and chemical toxicity.

Industrial temperature discharges notably affect fish disastrously in the higher ranges than in the lower. Also, high temperatures, may adversely affect the over-all biota by eliminating many organisms, but in doing so, allow a few, as certain heat resistant blue-green algae, *Phormidium,* to become dominant. Ranges in which algae are known to grow best in general are from 18 C to 30 C for diatoms, 30 C to 35 C for greens, and 35 C to 40 C for blue-greens, with some kinds growing at even higher temperatures (21). Gross limits of temperature that most warm-water fish are subjected to in natural bodies of water are somewhere between 0 C and 35 C (32 F to 95 F) (27). If waters of 86 F are available, warm-water fish may seek them, leaving 90 F water. Examples of warm-water fish are: sunfish, catfish, carp, and many minnows. Cold-water fish, as the salmonoids, salmon and trout, normally live in natural waters somewhere in the range between 32 F and near 65 F (summer temperature), and usually do not tolerate temperatures above 81 F. Certain trout have been reported as surviving temperatures of 82 F to 83 F for very short periods in natural waters (27, 52). The Aquatic Life Advisory Committee of the Ohio River Valley Water Sanitation Commission, in reference to waste discharges, recommended that temperatures shall not be raised above 34 C (93 F) ". . . at any place at any time," and that temperatures

during December through April should not exceed 23 C (73 F) ". . . at any place or at any time" (8). It is emphasized that, in streams suitable for trout propagation, temperatures shall remain unchanged from those of the natural water. Further, it has been stated that current knowledge does not permit a precise statement regarding the effects of varying temperature levels on the over-all biota of a stream. However, in general, it appears that in most temperate zone streams of low gradient, large reaches should not exceed 30 C for prolonged periods, and that headwater streams will probably have an upper limit of from 22 C to 25 C for extended lengths of time. It is pointed out that further research is likely to lower rather than raise these limits (20).

Turning to examples of high industrial heat discharges that have been recorded from field surveys and general observations, one can cite the Mahoning River in the Warren-Youngstown, Ohio, reach, the New Johnsonville steam plant on Kentucky Lake, the Martins Creek, Pennsylvania, steam-electric generating plant on the west bank of the Delaware River several miles downstream from Belvidere, New Jersey, and the Front Street power station on Lake Erie at Erie, Pennsylvania.

Published data indicate that temperatures in the Mahoning River have exceeded those that are tolerated by fish and other aquatic organisms. The "Ohio River Pollution Control" document (2), published by the United States Public Health Service, states, "During periods of low stream flow the water temperature below Youngstown has risen often to over 110 F." It is reported in "Water Resources of the Mahoning River Basin, Ohio" that, when the last of four reservoirs went into operation, flows have been such that the maximum daily temperatures have only occasionally been above 100 F, and that monthly mean temperatures have been below 98 F (22). During a 1952 July and September survey of the Mahoning (Pricetown to Lowellville reach) in which the senior author participated, temperature maxima for 12 stations occurred in September and were 35.1 C at Struthers and 34.5 C at Lowellville.

Fish were not taken through the use of seines and various dip nets in the reach of the Mahoning from below Warren through Lowellville in September of 1952 when industry was discharging its wastes, including heat, in addition to raw municipal sewage. At this time several chemical and physical factors, in addition to high temperatures mentioned above, could have been equally considered to be lethal or detrimental for fish, as for example: pH to as low as 2.4, DO as low as 0.2 ppm, and various high industrial and municipal sewage solids. In the part of July during the 1952 extended steel strike when

the total effect of pollution was largely that of raw domestic sewage and residual industrial effects, fish were taken at Girard and above Indian Run Creek in Youngstown. At Girard temperatures varied from 23.5 C to 29.5 C; DO varied from 5.0 to 5.6 ppm; and pH from 6.9 to 7.4. The fish taken here were the northern creek chub and the goldfish. Fish taken at the latter station under comparable temperatures and pH and DO ranges were the large-mouth black bass and the common shiner. At upstream control stations above Leavittsburg in July and September, with temperatures varying from 24 C to 31 C, the DO at from 5.7 to 6.9 ppm, and the pH from 7.0 to 7.6, a variety of fish was taken, as the white crappie, small-mouth black bass, the northern creek chub, green sunfish, northern black bullhead, bluntnose minnow, and the golden shiner.

A field survey of the fisheries related to heat discharged by the New Johnsonville steam plant on Kentucky Lake indicates that a localized warming effect, over that of contiguous waters in the impoundment, served to attract fish during cold-water periods, enabling them to survive (25). It is suggested that warm water from the steam plant may serve as a winter refuge for threadfin shad. These fish were found to be most abundant in the steam plant discharge harbor, warmed by condenser water discharges to 55 F, when other water of Kentucky Lake was 45 F.

Inconclusive information on the effects of hot condenser water discharges on aquatic life from a steam-electric generating plant which discharges to Martins Creek, Pennsylvania (which in turn, discharges heat to the Delaware River), has been published (54). These studies are continuing, which should reveal eventually conclusive information on the effect of heat loads on aquatic life in the Delaware in the vicinity of the power station. A graph that shows temperature dissipation in the area of the Delaware has a failing in lack of an exact scale of reproduction. It does serve to illustrate, however, how rapid temperature dissipation can be in a flowing stream. At a railroad bridge 1,500 ft below the heat source, the maximum temperature is 90 F; at 2,000 ft, 86 F; at 2,750 ft, 73 F; at 3,600 ft, 71 F; and at 4,500 ft, 68 F. The initial temperature of discharge water is not given.

EFFECTS OF PARTICULATE MATTER

Turbidity, which is considered to be an expression of the optical property of water which causes light rays to be scattered and absorbed rather than transmitted in straight lines, is caused by a variety of particulate suspended matter (Figure 2). Such matter may be, for example, living or dead phytoplankton or zooplankton cells, as algae,

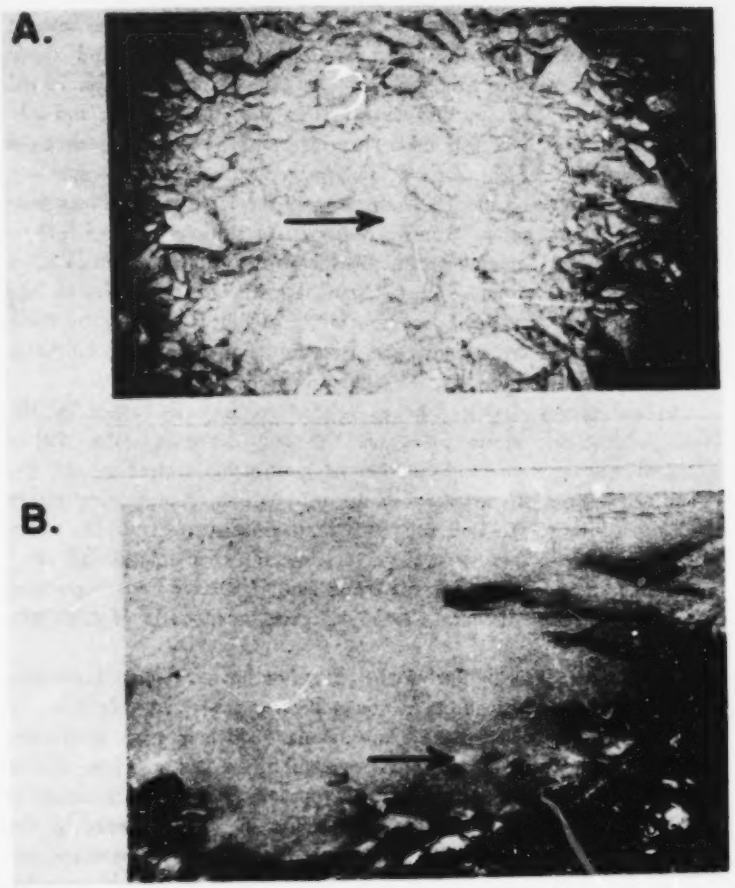

FIGURE 2.
Illustrating stream turbidity.

protozoans, bacteria, and small crustaceans, or silt or other finely divided inorganic as well as organic waste materials. Particulate matter in any form that settles to the bottom to form organic or inorganic sludge deposits is considered here as settleable solids. These solids would include among them, of course, settleable matter that is related to turbidity measurements.

Many industrial operations contribute turbidity and settleable solids to water, with resulting bottom deposits that affect aquatic life in varying severities. Rather than discussing the chemical changes that

may be wrought in water by such particulate matter, only the physical effects are considered here. Some industrial operations that can discharge particulate matter, which can be analyzed in terms of turbidity and settleable solids, are: metal, coal and other mineral mining, including coal washery; gravel washery; glass sand; lumber; aluminum; steel; pulp and paper; slaughter house; canning; tannery; milk and cheese; and oil.

Fine particulate inorganic and organic waste materials that remain in suspension can limit the penetration of sunlight, thus restricting the growth of attached bottom aquatic plants as well as floating or weakly swimming algal forms, which, in being photosynthetic organisms, are dependent on light for their existence. Also solids floc planktonic algae and animals out of water and carry them to the bottom to die. Thus, in limiting growths of aquatic plant meadows, food chains are interrupted, resulting in a sparsity of animal life.

As particulate matter settles to the bottom, deposits of settleable solids can blanket the substrate, forming undesirable physical environments for organisms that would normally occupy such a stream habitat if it were not being subjected to continual deposits of blanketing materials. It has been stated that erosion silt alters aquatic environments, chiefly by screening out light, by changing heat radiation, by blanketing the stream bottom, and by retaining organic material and other substances which create unfavorable conditions at the bottom (26). Also, it has been stated that the developing eggs of fish, as well as fish food organisms, may be smothered by deposits of silt (49). Too, it is indicated that direct injury to fully developed fish by nontoxic suspended matter apparently has been demonstrated convincingly only in tests with concentrations which are most uncommon in both natural and polluted water (24).

Bottom blanketing deposits consisting dominantly of organic solids and those of dominantly inorganic solids can have quite different physical effects on stream life. In the former instance, if marked toxicity does not exist and dissolved oxygen is satisfactory, stream life that is not adapted specifically to a bottom made up of soft organic sludges will be replaced by organisms that are adapted for life in such deposits. On the other hand, inert solids, as those from glass sand operations, coal washeries and mining mineral operations, typically destroy bottom life, there being a paucity of organisms that can live among compacted, heavy abrasives as represented by such wastes. These wastes may form actual "ball-mills" on a stream bottom, grinding and crushing life that is contacted, as materials may be resuspended and moved further downstream at high stream discharge periods.

The physical effects that organic sludges of industrial origin have in bringing about changes in bottom life are partially illustrated in Figure 3, which is a hypothetical situation based upon specific data that has been gleaned from information from those who have been participants on numerous field investigations. It is assumed, for this discussion, that appreciable toxicity does not exist and that the dissolved oxygen resources are not inimical to aquatic life. Settleable solids enter the stream at Mile 0 and organic sludge deposits of maximum thickness exist in the zone of active decomposition between Miles 12 and 48. Turbidities are highest between Miles 0 and 12. Sludge deposits are not appreciable elsewhere or are nonexistent, and turbidities are also unimportant elsewhere.

In the clean water zones the bottom is composed of small and large stones. Here there is found a multitude of different species of bottom organisms, plankton, and fish. Fish nesting areas are numerous. The typical association of clean water nonsludge dwelling animal species are: caddisfly larvae, stone flies, mayflies, hellgrammites, gill-breathing snails, and unionid clams. Small-mouth black bass, sunfish, and various minnows abound here. Numerous planktonic algal species are present. Thus, in the unpolluted zones there is a great variety of species of organisms represented by a few individuals (Figure 3).

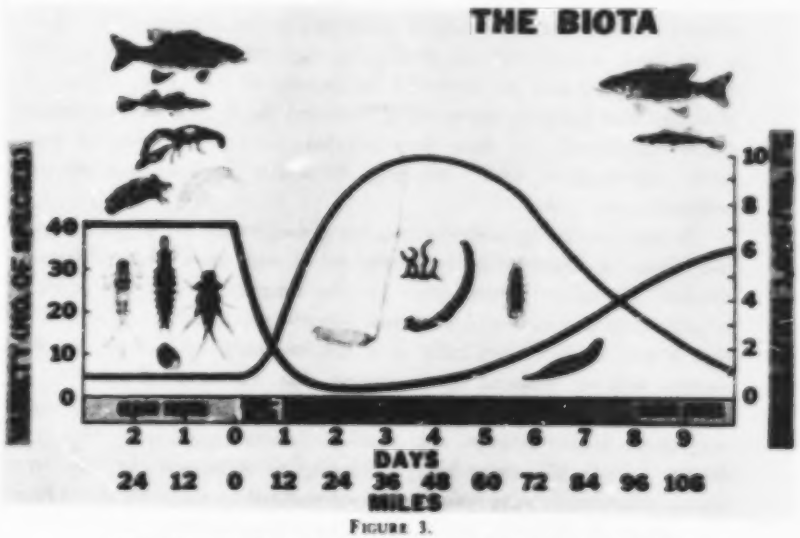

FIGURE 3.

The physical effects that organic sludges of industrial origin have in bringing changes in bottom life.

In the zone of degradation, floating solids that become settleable ones blanket out light penetration and, on moving into the zone of active decomposition, settle to form sludge deposits over the entire bottom. Turbidities here are high. Only a few species of organisms can survive on the soft, shifting blanket of sludge. Such species, in being isolated from many predators, here form huge populations of individuals (Figure 3). Solids, in settling, floc floating plankton out of water; thus they are scarce. The few animal forms that are adjusted to living in a sludge substrate are blood worms, *Tubifex* and *Limnodrilus*, water sow-bug crustaceans, *Asellus*, certain left-handed snails, and various leeches. Fish are absent or are scarce and prefer to form their nests elsewhere. Higher submerged aquatic plants are absent, not being able to root in such sludge deposits. Species of algae are extremely scarce, being represented by dominating blue-greens as *Phormidium* and *Oscillatoria*, which form gelatinous slimy blankets over the sludge in shallow marginal water. Only an occasional plankter moves through the water in the zone of active decomposition, most having been flocked out of the upstream water in the zone of degradation.

The physical effects of inert inorganic solids, as from glass sand operations, can be more severe in reducing aquatic populations than the resulting reduction in them by settleable organic solids. Data collected in September 1952 (Figure 4) and again in September 1958 vividly relate the physical effect on aquatic life of mineral particulate matter wasted from a glass sand operation to the Potomac River from a small creek. Below this creek, into which wastes are discharged from where they are carried to the Potomac, the true "Sahara Desert" of waters is found, with oases being extremely sparse. In 1958, above the point of confluence, the Potomac was unaffected by unnatural turbidities and by inert sludge blankets. The sparkling clear Potomac is bedded by a bottom of rocky ledges, rocks, coarse gravel and some naturally occurring clean sand. Beds of higher aquatic plants, as [redacted] *Elodea* and *Potamogeton*, lushly abound. Gill-breathing snails and mayflies dominate the invertebrate fauna and are found everywhere on the substrate. Large unionid, pearl-button clams are common marginally. Minnows are observed in abundance and the filamentous alga, *Cladophora* covers much of the rocky area. A total of eleven genera of planktonic and filamentous algae and eight genera of animals are represented in the collections from this station.

At a station 600 yds below the confluence of the small creek (receiving glass sand wastes) the bottom of the river was devoid of life in 1958, as it was in 1952. Blue-green algae grew marginally on

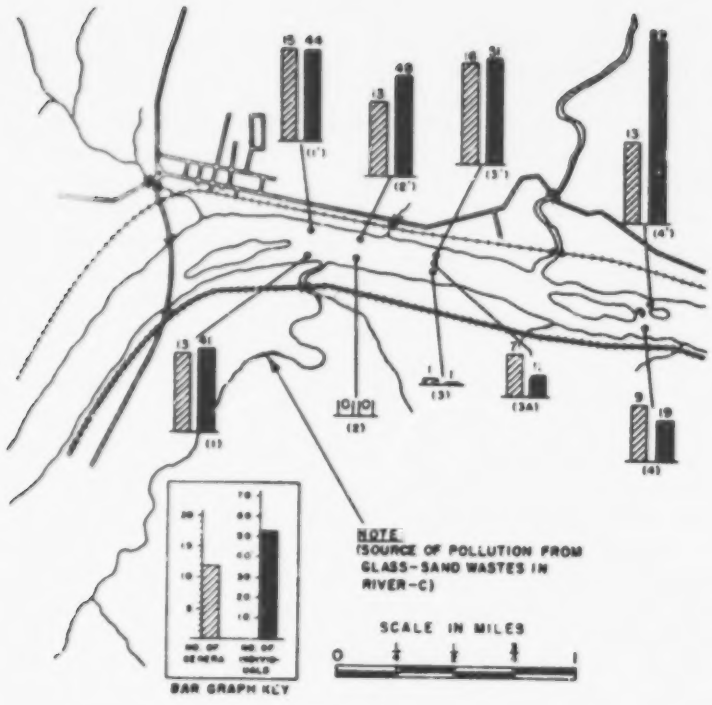

FIGURE 4.
Total genera and individuals of bottom animals per sq. ft., River-C (Sept. 1952).

the wave-washed area of the bank. This paucity of organisms existed to midstream where three genera of snails and ten genera of planktonic algae were collected. From the left bank* to midstream, rocky ledges, rocks, gravel and sand of the original Potomac River bottom were completely covered by a blanket, up to two feet deep, of wasted glass sand fines. During the period in which 1958 samples were collected the water was clear and the sand fines desert was spectacularly visible. Turbidities (Figure 2) attributable to this operation were found to vary tremendously in 1958 with varying waste discharges, as from 130 units to 50,000 units. The effects of such deposits in 1958 were observed to suppress bottom organism abundance as far as ten miles downstream.

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* Public Health Service stream banks are referenced looking upstream.

that should be referred to in experimental studies, are Bibliography References 19 and 31.

On field investigations and from reconnaissance observations, *Sphaerotilus* has been observed to abound in certain reaches of the Columbia River, Washington and Oregon; Altamaha River, Georgia; Hiawasee River, Tennessee; New River, Virginia; Penobscot River, Maine; Clearwater River, Idaho; Fox and Menominee Rivers, Wisconsin, and Bear River, Utah.

It has been observed in restricted patches in the Connecticut River, Massachusetts; Ohio River, downstream from Cincinnati, Ohio; Grass River, New York; Potomac River drainage in Maryland; South Holston River, Tennessee, as well as in various smaller streams throughout the country.

An inventory is badly needed to indicate the current abundance of *Sphaerotilus* in various waterways of the United States. Thus, only when such data are presented in a single document can a valid assessment be made of its distribution and magnitude of nuisances that it causes in interfering with various water uses. Too, only such a document can relate the subtleties of its development to bloom proportions to nutritional substrates from various types of industry, municipal sewage, and agricultural runoff or to some combinations of these.

Sphaerotilus has become recognized as a pest in recent years, principally because of its interference with both commercial (Figure 5) and sport fishing. Its especially nuisance effect on the gill-net commercial fisheries of the Columbia River is well known. Specific complaints have also been voiced by fishermen on the Altamaha River in Georgia and the New River in Virginia. Realistic complaints are made basically to the effect that *Sphaerotilus* flocs become entangled in various fishing gear, thus reducing their efficiency (34, 11).

Sphaerotilus, in forming blooms, especially in riffle areas with other associated bacterial slimes, may blanket the bottom, thus "crowding out" fish food organisms and destroying potential fish nesting areas. The "crowding out" effect on desirable organisms by various slimes has been considered by a number of persons (14, 45, 52, 57, 58).

Difficulties that *Sphaerotilus* can cause that could develop in time, which have not yet been reported to us, are: (1) clogging of rapid sand filters of municipal and industrial water treatment installations; (2) formation of tastes and odors in water as it decays; (3) creating mucilaginous nuisances in pumping stations and in irrigation canals; and (4) a contact nuisance in water recreation, as swimming, water

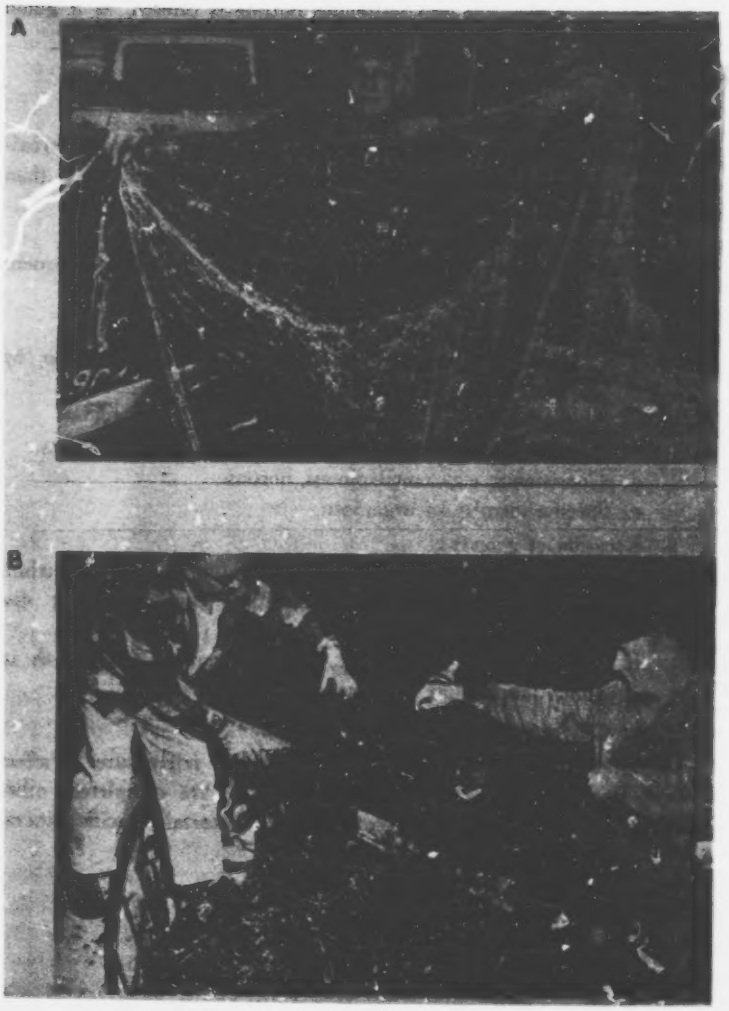

FIGURE 5.
Sphaerotilus interferes with both commercial and sport fishing.

skiing, and boating. To enable those working with water to assess the extent of development of *Sphaerotilus* in the field and to relate it to potential difficulties, the following outline is offered, as a guide for recording observations on this slime:

A. Growth Characteristics

1. Presence of attached and/or floating growths.
   a. Relation of attached to dispersed growth and their approximate quantitative relationship. Is there more attached than floating growth, or vice versa?
   b. Description of surfaces to which growths are attached.
   c. Evidence of settling of floating growths and subsequent growth or decomposition.
2. Description of attached and/or floating growths.
   a. Color: white, discolored, evidences of decomposition by blackening of (older) portions.
   b. Approximate size of flocs.
   c. Presence of inanimate material, e.g., grit, cellulose fibres.
   d. Consistency, e.g., mucilaginous, fibrous.
   e. Specific identity of organism.
3. Location of growths.
   a. In relation to domestic and/or industrial waste outfall. Point of first visible manifestation and subsequent disappearance.
   b. In relation to depth, e.g., relative amounts of growth in riffles and shallow portions versus deep pools.

B. River Characteristics

These are based upon criteria which are fairly sure to affect the growth. As more precise investigations are completed, other data may be critical, e.g., the concentration of certain specific mineral substances.

1. BOD.
2. Temperature.
3. Dissolved oxygen.
4. Organic nitrogen.
5. Inorganic nitrogen.
6. Phosphate.
7. Hardness.
8. Depth.
9. Velocity of flow (ft/sec).
10. Volume of flow of river (cfs).

C. Associated Nuisances, if any
   1. Water treatment installations.
      a. Filter clogging.
      b. Tastes and odors.
   2. Irrigation projects.
      a. Pumping station difficulties.
      b. Irrigation canal and pipe difficulties.
   3. Recreation.
      a. Interference with boating.
      b. Interference with water skiing.
      c. Interference with swimming.
   4. Fish and wildlife.
      a. Interference with commercial fishing.
      b. Interference with sport fishing.
      c. Interference with fish spawning and nesting areas.
      d. Interference with wildlife propagation.

ALGAL BLOOMS

Data relating to extensive plant growths, water meadows, show that inorganic and organic nutrients containing nitrogen and phosphorus are among the major factors that contribute to plant abundance including algal blooms. In modern waste treatment practices dissolved inorganic or mineral constituents of municipal sewage and industrial wastes are removed only incidentally by sedimentation and oxidation. Also certain organic materials are broken down, with treatment, to liberate inorganic nitrogen and phosphorus, thus making them more available as fertilizers for plant growth. Treatment plant effluents may actually contain more readily available nutritional substrates than are found in raw sewage effluents. Thus, in order to prevent acceleration of the fertilizing effect of sewage and of certain nontoxic industrial wastes and attendant nuisance problems, all such wastes ideally should be excluded from natural lakes and impoundments. In spite of exclusion of nutrient-bearing wastes, agricultural drainage, carrying nitrogenous and phosphorous compounds, will especially provide nutrients that may encourage nuisances in certain regions.

It has been shown that, if assets of inorganic nitrogen and phosphorus exceeded 0.30 and 0.01 ppm respectively, at the start of the active growing season (the time of spring turnover in northern climates), a season with nuisance blooms could follow (47). This suggestion was made following two years of study on 17 lakes in southeastern Wisconsin and, undoubtedly, does not apply in strict

manner to all lakes. At least it has served the purpose of stimulating investigations along the lines of obtaining better information (47).

The facts today indicate that, with continual nutrient enrichment of waters with certain industrial wastes, sewage and agricultural fertilizers, through runoff, algal nuisances have only just begun to disclose what nuisance monsters they can become in future years. Domestic sewage alone may vary in its nitrogen content from 15 to 35 ppm and in phosphorus from two to four ppm (48). In relation to these nutrients, it has been stated: "A large percentage of these fertilizing elements exists in a readily available condition or becomes so during biological treatment or while undergoing stabilization by microorganisms in the receiving body of water. Consequently, it can be reasoned that sewage contains nitrogen and phosphorus in a ratio of about eight to one" (48).

Data on increments of nitrogen and phosphorus from various industrial operations are not at hand; however, such can be important in nurturing algal nuisances. Many pounds of industrially produced water softeners and synthetic detergents are now added to our waterways. Some 1,200,000,000 pounds were marketed in 1950. *Chemical and Engineering News* in 1951* predicted a potential consumer market in 1952 of some 2,000,000,000 pounds of synthetic detergents a year. Specific contributions by agriculture of nitrogen and phosphorus to bodies of water by runoff are not known. However, data provided us by the U. S. Bureau of Reclamation point to increments of nutrients that might be related to the over-all bloom situation.† A 1955 estimate of an average use of fertilizer per irrigated acre in California is 382 lbs, of which 42 lbs per acre are nitrogen and 26 lbs per acre are P_2O_5.

The effects of algal nuisances have long been known to the water works field. Algal blooms cause tastes and odors in water, they clog rapid sand filters, and they form unsightly scums on various basins in water treatment installations (32, 38, 39, 40, 41). The writers wish to re-emphasize problems that can in future years greatly plague those charged with management of water projects, such as the many multiple purpose reservoirs that are being constructed in this country. At the heart of biological nuisance problems there will especially be algal blooms which will be nurtured by nutrients from various sources. In

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* Vol. 22, p. 554 (1951).

† Personal communication, 12/8/53, from A. N. Murray, Bureau of Reclamation, Region II, Regional Office, U. S. Department of the Interior, Sacramento, California.

summarizing information for European lakes, data is used to illustrate biological nuisance potentials that can arise, with time, in our now "new reservoirs" (30).

Enrichment of water is called eutrophication. But little has been published on lake fertilization to show systematically the effects of nutrients on the entire ecology of a lake, and on man's ultimate uses of lake water (30).

In using Lake Zürich, Switzerland, a lake composed of two arms connected by a narrow channel, as an example, it is stated that less than 100 years ago both arms were clear, clean and supported trout and whitefish. Since the turn of this century urban drainage from small communities totaling about 110,000 persons has been discharged to one basin of this lake. Concurrent with increased urban fertilization, beginning in 1896, algal scums formed that were malodorous as well as unpleasant to the eye. The lake ceased to be attractive for bathing, boating and general vacationing. The cities and industries that used lake water had to install expensive "filtering and purifying systems" to remove greatly increased numbers of organisms and then obnoxious tastes and odors. Oxygen became deficient in the deeper water, resulting in the disappearance of trout and one species of whitefish, with two other species of whitefish becoming scarce. Other fish, largely coarse fish species, have replaced the sought-after game fish.

The shallower basin, Obersee, which received no urban drainage, still is reported to retain its "virgin-lake" characteristics, and has changed but little. It is quite clear that unwitting fertilization not only causes nuisances, but likewise hastens the extinction of a lake by encouraging more rapid sedimentation (30). This latter remark is not just based on Lake Zürich but upon records for 37 lakes in the United States, Austria, England, Finland, Germany, Italy, and Sweden, where cultural enrichment has entailed disagreeable consequences within several decades, that are similar for the most part to the happenings in Lake Zürich (30).

The effects of algal blooms on lakeside dwellers have been well documented for certain lakes in the Madison, Wisconsin, area. Especially during hot summer periods algal blooms have accumulated to give lakes a thick green peasoup appearance and consistency. At times of blooms lakes are no longer inviting to bathers and fishing may be impaired. Boating becomes a sport out of season as long as unsightly masses of green persist and vile odors, produced on decomposition, permeate the area. The odors of decomposition may make life in the area hardly bearable, and may necessitate change in residence (35).

Algal blooms have been related specifically to fish kills through removal of dissolved oxygen from water in respiration. During daylight hours algae and submersed aquatic plants give off oxygen by photosynthesis, commonly raising the dissolved oxygen resources to supersaturation levels. Photosynthesis does not occur during hours of total darkness. Respiration, of course, continues over 24 hrs with algal and other aquatic plants as it does with animals. In streams with huge algal blooms, dissolved oxygen can be removed by respiration by the organism mass to where oxygen resources may be reduced to asphyxial levels resulting in kills.

For example, in Lytle Creek, Wilmington, Ohio, dissolved oxygen was observed to fluctuate over 24 hrs from 19.4 ppm in the afternoon to 0.7 ppm before dawn. A fish kill occurred in this creek that was attributable to low dissolved oxygen levels resulting from depletion attributable to organism respiration (52). Fish kills relating to oxygen depletion have also been reported for East Okoboji Lake and Storm Lake, Iowa (44). Disastrous reductions for aquatic life of dissolved oxygen resources during early morning hours, based on field surveys of streams in the Ohio River Basin, have been discussed (17). The reduction of dissolved oxygen to levels endangering aquatic life during night time hours and during a consecutive series of cloudy days when oxygen production is curtailed has also been thoroughly reported (37).

RELATIONSHIP OF RADIOACTIVE WASTES TO AQUATIC LIFE

We do not propose to discuss maximum permissible doses of radioactive substances for water or to relate them to aquatic life. We only desire to re-emphasize that certain isotopes through adsorption and absorption by organisms can be cycled into direct human food chains (Figure 6) (53). It is further emphasized that radioactive isotopes can be concentrated in high orders of magnitude, over that of "pure" water, by organisms that are living in blooms in natural waters (Figures 7 and 8)* (23).

Concentration of radioactive materials in edible fish and from them to humans is readily visualized. More subtle is the potential transport of radioactive materials into humans from raw water sources after algal blooms have increased the concentration (Figure 7). Even

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* Figures 7 and 8 were supplied through the courtesy of Dr. R. F. Foster, Manager, Aquatic Biology, Biology Operation, Hanford Atomic Products Operation, General Electric Company, Richland, Washington. The original figures appeared in the 1958 paper of Davis and Foster. (23)

Radioactive Wastes from Water to Man

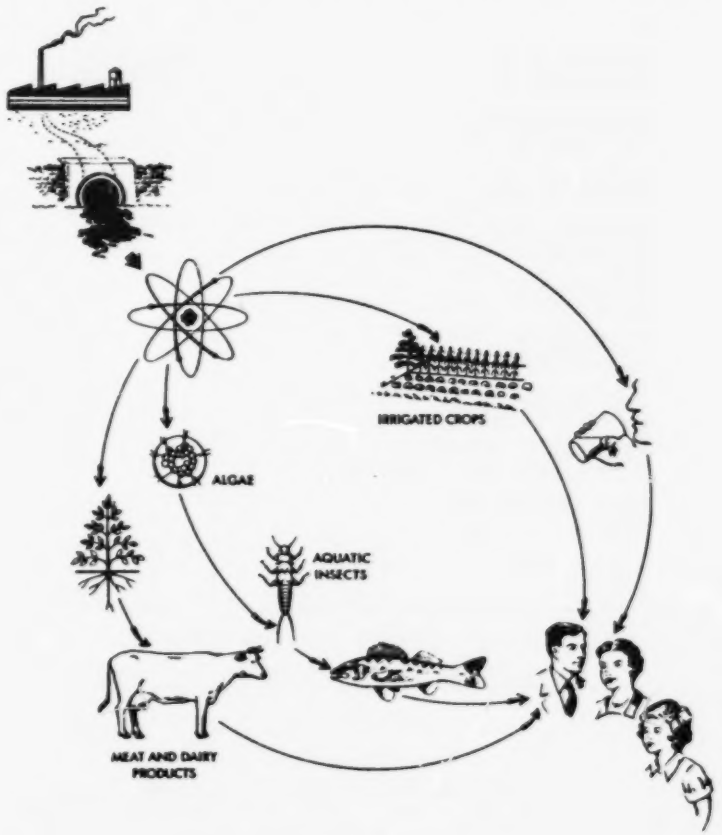
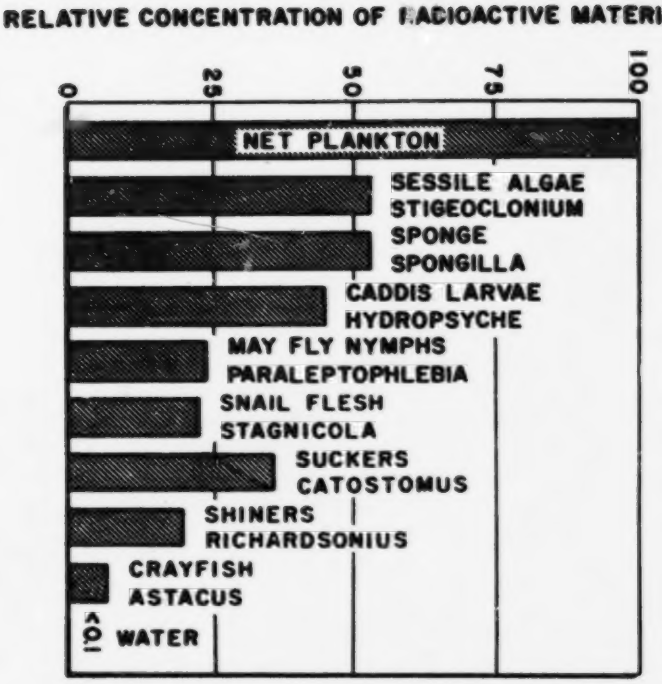


FIGURE 6.
Radioactive wastes from water to man.

though such blooms are caught on rapid sand filters and backwashed to waste, there is a potential pathway for materials to pass through the filters into finished water, as algal cells may fragment on filters to release their dissolved solids content. Water supplies without any treatment except chlorination can carry algal cells with adsorbed and absorbed radioactive materials directly into the human body.

In considering the bioaccumulation of radioisotopes, it has been pointed out that there are many radioisotopes, however, that are not



RADIOACTIVITY IN DIFFERENT COLUMBIA RIVER ORGANISMS

FIGURE 7

FIGURE 7.

Relative concentration of radioactive materials.

biologically concentrated (23). It has been stated that: "With an increasing number of atomic energy installations and their associated problems of disposal of liquid wastes, we recognize that more and more aquatic environments are going to be exposed to at least low concentrations of radioactive materials. For the safety of human populations who may be drinking water which contains such radioactive materials, a set of maximum permissible concentrations has been recommended. by the (International Commission on Radiological Protection, in 1955) By themselves, however, such recommendations are inadequate to define completely the radiological hazard which may develop through aquatic food chains. Where biological systems are

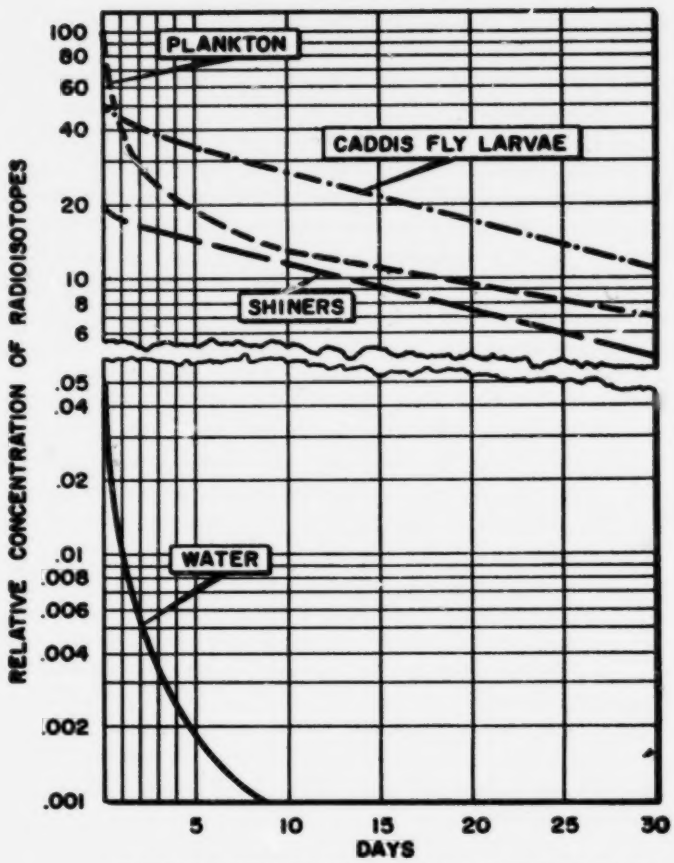


FIGURE 8.

Concentration of radioactive isotopes.

involved, the organisms may accumulate certain isotopes to many times the initial concentrations in the water" (23).

At the International Conference on the Peaceful Uses of Atomic Energy, information pertinent to our discussion of the subtleties of radioactive concentration by organisms, as such can be related to human food and potable water supplies, was enlarged upon (28). "Extensive studies have been made of the radioactivity in river organisms

below the Hanford reactors since the radiation levels could not accurately be predicted. Results indicate that concentration of very short-lived isotopes is of limited consequence in higher organisms such as fish. Radiophosphorus, on the other hand, is concentrated more than one hundred thousand times. Although the P^{32} is highly concentrated, existing amounts in the Columbia River are well below dangerous levels. Even in the most radioactive section, the young fish receive only about 0.1 rad per day from beta emitters—far less than the amount which would produce discernible damage. Both laboratory and field studies of river forms have shown no injurious effects from the presence of the reactor effluent. It is questionable that widespread decimation of aquatic populations will occur from radiation damage in situations where contamination levels in fish must remain below maximum permissible levels for human food. The difference in the activity density of Columbia River fish over that of the water, owing to the tremendous power of aquatic forms to concentrate some radioisotopes, illustrates the need for careful consideration of potential hazards prior to disposal of liquid wastes to public waters. If radiophosphorus were allowed to reach the maximum level permitted for drinking water, organisms living in the water would suffer radiation damage and the fish would be unsafe for human food. The seriousness of radioactive contaminations in an aquatic environment depends not only upon the quantities of individual isotopes which may be released but also upon the physical, chemical, and biological properties of the water. When contamination of a river or lake may be significant, careful investigation of each particular case is essential since complex biological processes may introduce hazards not included in such conventional limits as permissible concentrations for drinking water."

GRAPHICAL PRESENTATION OF BIOLOGICAL DATA

Graphical presentation of biological data may often be more effective in demonstrating the impacts of pollution on aquatic life, for the general report reader, while long lists of names of animals and plants will not perform the same function. Several meritorious schemes for reporting biological data collected on pollution surveys have been published during the last few years (15, 16, 42, 43, 60).

Figure 9 illustrates the use of a vertical bar graph in presenting a summary of the abundance of total genera of invertebrate animals and plants in a river as such are related to pollution (fish are excluded). This figure summarizes, simply, seven typed pages of tabular data

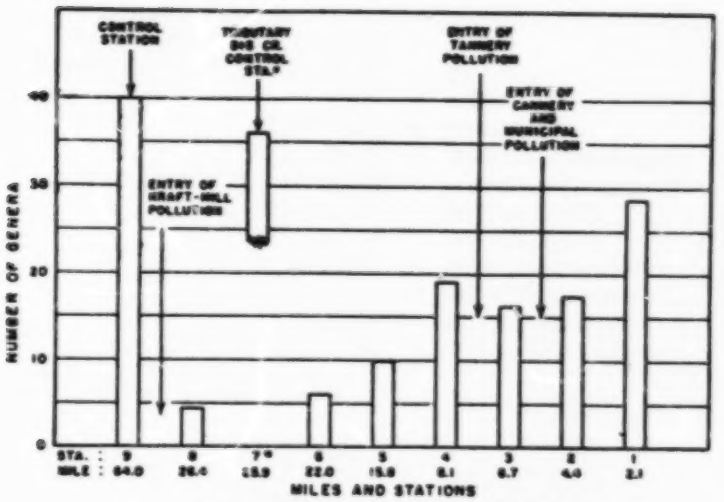


FIGURE 9.

Illustration of a vertical bar graph.

dealing with generic names of aquatic animals and plants found at each of nine stations distributed over 61.9 miles of "River B." Station 9 is a control station above major sources of municipal and industrial pollution. Station 7 is another control station, on an unpolluted tributary stream that enters the main river at Mile 25.9, between Stations eight and six where pollution has exerted its maximum effects in suppressing the variety of kinds of animals and plants. Other bars reflect the abundance of animals and plants at stations as related to varying gross effects of pollution on the river.

Figure 10 illustrates the use of horizontal bar graphs to summarize lengthy tabular data often left dangling in the appendix of a report. This figure demonstrates how three bar graphs may be combined to present a summary biological picture on a single page. If each graph were presented on a separate page, correlation, in telling the effects of pollution on the total kinds (genera) of animals and plants, would be less coherent. The collections of aquatic life, on which this plate is based, were made in July and September 1952 in "River A." The July collections were gathered after industrial production was curtailed as a result of a strike, and the great load of sustained pollution was from raw domestic sewage. September col-

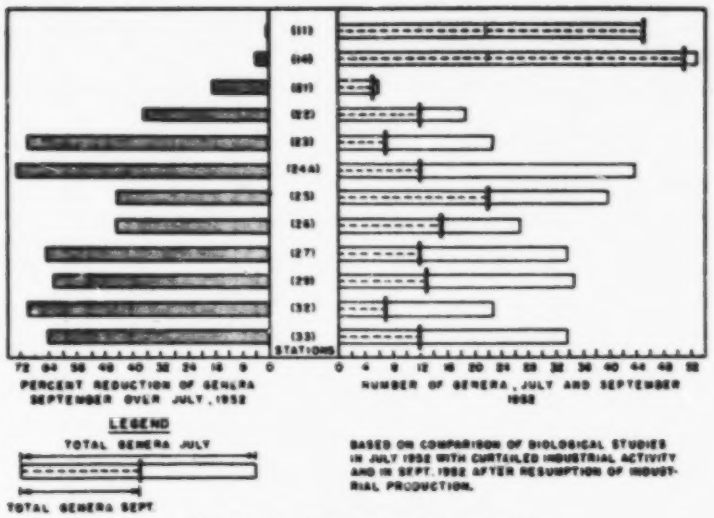

STATIONS
PERCENT REDUCTION OF GENERA SEPTEMBER OVER JULY, 1952
NUMBER OF GENERA, JULY AND SEPTEMBER 1952
LEGEND
TOTAL GENERA JULY
TOTAL GENERA SEPT.
BASED ON COMPARISON OF BIOLOGICAL STUDIES IN JULY 1952 WITH CURTAILED INDUSTRIAL ACTIVITY AND IN SEPT. 1952 AFTER RESUMPTION OF INDUSTRIAL PRODUCTION.
EFFECT OF INDUSTRIAL WASTES ON TOTAL GENERA OF ORGANISMS, RIVER-A

FIGURE 10.

Illustration of a horizontal bar graph.

lections were made at the same stations after industrial production was resumed and resulting wastes were added to the river to those from municipalities. Variations in the total genera of animals and plants in July and September are shown on the right of the plate. Stations 11 and 14 represent control upstream stations. All other stations (21-~~23~~)[33] are subjected to varying loads of municipal and industrial pollution. On the right are shown the suppressing effect of industrial pollution (September collections) on kinds of biota when such were added to that of municipal sewage pollution (July collections). Variation in numbers of genera of plants and animals between July and September is not a result of any significant seasonal variation as is demonstrated in similarity of abundance in July and September at control Stations 11 and 14. The left portion of Figure 10 shows the per cent in reduction of genera of animals and plants after resumption of industrial pollution.

Figure 4 demonstrates the use of vertical bar graphs, superimposed over a pictorial map of an area, to show variation in bottom animals per square foot of sample in "River C." This graphical presentation allows one to locate sampling stations at a glance in relation to roads,

railroads, and towns. Illustrated are the effects that inert, inorganic solids may have in limiting the number of kinds and individuals of bottom animals (Stations 2 to 4 on the south side of the river), compared with bottom animal abundance at stations in unaffected stream areas (Station 1 on south side and 1′, to 4′, on the north side). Station 1 and 1′ represent control stations. Solids are carried into the main river from the tributary at the confluence between Stations 1 and 2. Bottom animals are absent at downstream Station 2. Only one genus was collected at Station 3 on the south half of the bottom, while seven genera were taken in the center of the river (3A), and 16 genera on the bottom of the northern half of the stream (3′).

BIOLOGICAL SAMPLERS USEFUL

In general, it is recommended that sampling be carried out on industrial waste surveys so that all components of the flora and fauna will be sampled. Thus, animal and plant associations can be established that vary in tolerance to gross pollution of various sorts. In lieu of such collecting, sessile attached algae and bottom animals, that can be readily sampled at a fixed station, will present quite specific information on the effects of gross pollution on aquatic life in any reach of a stream.

In collecting samples of the over-all biota on an industrial waste stream survey, a variety of samplers will have to be used to effectively sample bottom organisms in deep and in shallow water, to sample organisms in weed beds, and to collect organisms from flowing water. Dredges that have proved successful in collecting bottom organisms from deep water in many streams, lakes, and estuaries are the Petersen (Figure 11-A) and Ekman (Figure 11-B). A successful bottom sampler in shallow riffle areas is the Surber square foot sampler (Figure 12-A, B). A plankton net (Figure 12-C) is effective in collecting floating zooplankton and phytoplankton from the water surface, while the Kemmerer bottle (Figure 13-A, B) is useful in collecting such organisms in deeper waters. A hand net with a canvas skirt (Figure 12-D) is useful in obtaining organisms from weed beds and algal masses. Seines of various dimensions are available for the capture of fish.

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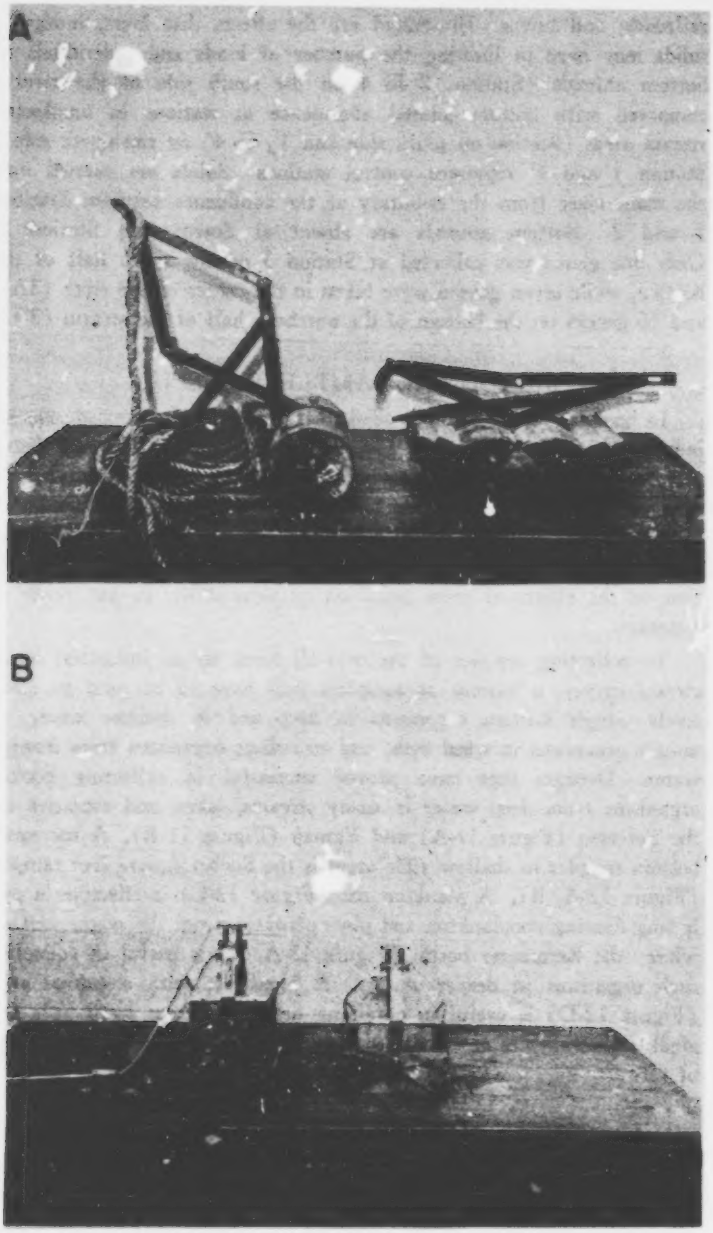

FIGURE 11.
Dredges for collecting bottom organisms
A. ~~Peterson~~ Petersen Dredge, B. Ekman Dredge.

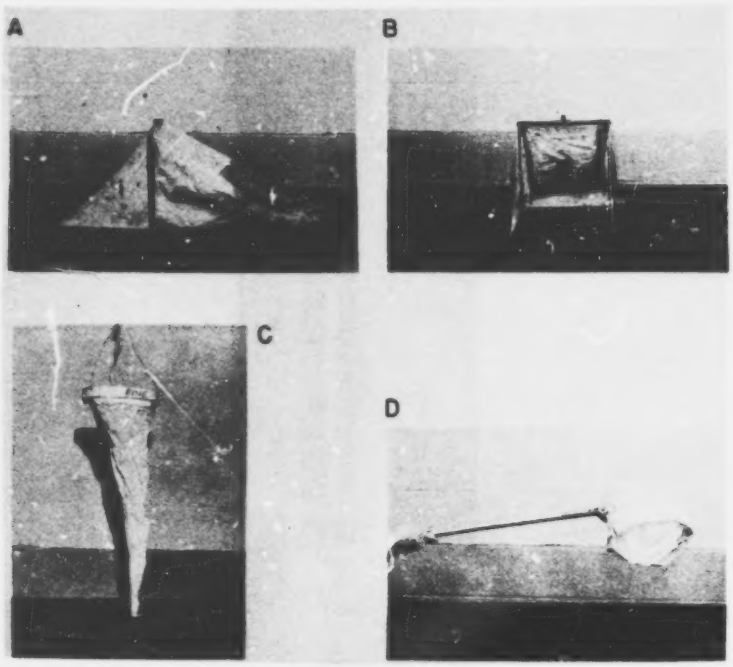

FIGURE 12.

Shallow riffle Sampler A and B Surber sampler; plankton net, C; hand net, D.

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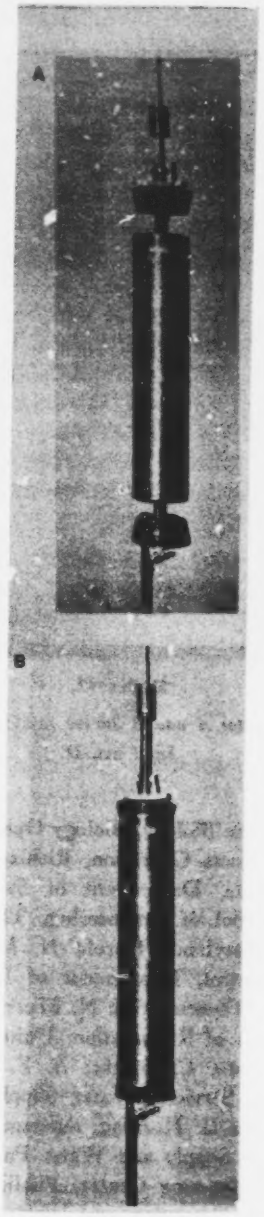

FIGURE 13.
Plankton deep water sampler, Kemmerer type.

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BIBLIOGRAPHY

1. Amberg, H. R., and Elder, R., "Intermittent Discharge of Spent Sulphite Liquor," *Proc. Amer. Soc. Civ. Engrg.*, Vol. 82: SA-2, paper No. 929, 12 pp., 1956.
2. Anon., Ohio River Pollution Control, Report of the U. S. Public Health Service, House Document No. 266, Pt. 2, p. 417, 1944.
3. Anon., Ohio River Drainage Basin, Fed. Security Agency, Public Health Service, *Water Poll. Series*, No. 12, p. 1-178, 1951.
4. Anon., "The Big Stink at Erie," *Pennsylvania Angler* (May), 3-4, 1953.
5. Anon., "Report of Water Pollution Study Mahoning River," Water Poll. Control Unit San. Engrg. Div. Ohio Dept. of Health, Columbus, Ohio, p. 1-91, 1954.
6. Anon., "Aquatic Life Water Quality Criteria: First Progress Report," *Sew. and Indust. Wastes*, Vol. 27:3, p. 321-331, 1955.
7. Anon., "Gizzard Shad Blackout Erie," *Pennsylvania Angler* (January), p. 15, 1956.
8. Anon., "Aquatic Life Water Quality Criteria: Second Progress Report," *Sew. and Indust. Wastes*, Vol. 28:5, p. 678-690, 1956*a*.
9. Anon., "Coal River Gets 15,000 Bass," *West Virginia Conservationist*, Vol. 19:11, p. 28, 1956*b*.
10. Anon., "Rogue River Rogues," *Sports Fishing Institute Bull.*, No. 66, p. 1-2, 1957.
11. Anon., Report on Pollution of Interstate Waters of the Lower Columbia River, Bonneville Dam to Cathlamet, Washington. U. S. Dept. of Health, Education, and Welfare, Public Health Service, p. 1-32 (Appendix A), 1958.
12. Anon., Transcript of Conference in the Matter of Pollution of Interstate Waters, Lower Columbia River, Bonneville Dam to Cathlamet, Washington. (Sept. 10-11, 1958, at Portland, Oregon). Dept. of Health, Education, and Welfare, Public Health Service, Water Supply and Water Pollution Control Program, Washington, D. C., p. 1-165 (Appendix A), 1958*a*.

13. Anon., "Columbia River Study, 1956-58 Progress Report," Joint Study by: Washington Poll. Control Com. and Crown Zellerbach Corp., p. 1-61, 1958*b*.

14. Bartsch, A. F., "Biological Aspects of Stream Pollution," *Sew. Works Journ.,* Vol. 20:2, p. 292-302, 1948.

15. Beck, W. M., Jr., "Studies in Stream Pollution Biology, Pt. I. A Simplified Ecological Classification of Organisms," Quart. *Journ. Fla. Acad. of Sci.,* Vol. 17:4, p. 211-227, 1954.

16. Beck, W. M., Jr., "Suggested Methods for Reporting Biotic Data," *Sew. and Indust. Wastes,* Vol. 27:10, p. 1193-1197, 1955.

17. Brinley, F. J., "Sewage, Algae, and Fish," *Sew. Works Journ.,* Vol. 15:1, p. 1139-1152, 1943.

18. Burdick, G. E.; Dean, H. J.; and Harris, E. J., "Toxicity of Emulsifiable Rotenone to Various Species of Fish," *N. Y. Fish and Game Journ.,* Vol. 2, p. 36-67, 1955.

19. Butcher, R. W., "Contributions to Our Knowledge of the Ecology of Sewage Fungus," *Trans. Brit. Mycological Soc.,* Vol. 17, p. 112-124, 1932.

20. Cairns, J., Jr., "Effects of Heat on Fish," *Indust. Wastes* (May-June), p. 180-183, 1956*a*.

21. Cairns, J., Jr., "Effects of Increased Temperatures on Aquatic Organisms," *Indust. Wastes* (March-April) reprint, 3 pp., 1956*b*.

22. Cross, W. P.; Schroder, M. E.; and Norris, S. E., "Water Resources of the Mahoning River Basin with Special Reference to the Youngstown Area," *U. S. G. S. Cir. No. 177,* p. 1-57, 1952.

23. Davis, J. J., and Foster, R. F., "Bioaccumulation of Radioisotopes through Aquatic Food Chains," *Ecology,* Vol. 39:3, p. 530-535, 1958.

24. Doudoroff, P., "Water Quality Requirements of Fishes and Effects of Toxic Substances," Chapt. IX in M. E. Brown, Vol. II (Behavior), *The Physiology of Fishes,* Acad. Press Inc., N. Y., p. 403-430, 1957.

25. Dryer, W., and Benson, N. G., "Observations on the Influence of the New Johnsonville Steam Plant on Fish and Plankton Populations," *Proc. 10th Annual Conf. Southeastern Assoc. of Game and Fish Commissioners,* p. 85-91, 1957.

26. Ellis, M. M., "Erosion Silt as a Factor in Aquatic Environments," *Ecology,* Vol. 17:29, p. 29-42, 1936.

27. Ellis, M. M., "Detection and Measurement of Stream Pollution," U. S. Bur. of Fisheries, *Bull. No. 22,* p. 365-437, 1937.

28. Foster, R. F., and Davis, J. J., "The Accumulation of Radioactive Substances in Aquatic Forms," International Conf. on the Peaceful Uses of Atomic Energy, No. A/CONF.8/P/280, U. S. A., p. 1-7, 1955.

29. Fry, F. E., "Some Temperature Relations of Fish." reprinted (1 page) from Federation Proc., March, Vol. 10, No. 1, Pt. 1, 1951.

30. Hasler, A. D., "Eutrophication of Lakes by Domestic Drainage," *Ecology,* Vol. 28:4, p. 383-395, 1947.

31. Höhnl, G., "Nutritional and Metabolic Investigations of *Sphaerotilus natans,*" Archiv. für Mikrobiologie, Vol. 23, p. 207-250, (translated by Kresge-Hooker Sci. Library Service), 1955.

32. Ingram, W. M., and Palmer, C. M., "Simplified Procedures for Collecting, Examining, and Recording Plankton in Water," *Journ. Amer. Wat. Works Assoc.,* Vol. 44:7, p. 617-624, 1952.

33. Ingram, W. M., and Doudoroff, P., "Selected Bibliography of Publications on Industrial Wastes Relating to Fish and Oysters," Public Health Biblio. Series No. 10, Public Health *Service Publ. No. 270,* p. 1-28, 1953.

34. Lincoln, J. H., and Foster, R., "Report on Investigation of Pollution in the Lower Columbia River," Wash. State Pollution Control Com. and Oregon State *San. Auth.,* p. 1-143, 1943.

35. Mackenthun, K. M., "The Chemical Control of Aquatic Nuisances," Com. on Water Pollution, Madison, Wisc., p. 1-64, 1958.

36. Morgan, E. H., and Beck, A. J., "Carbohydrate Wastes Stimulate Growth of Undesirable Filamentous Organisms in Activated Sludge," *Sew. Works Journ.,* Vol. 1:1, p. 46-51, 1928.

37. Olson, T. A., "Some Observations on the Interrelationships of Sunlight, Aquatic Plant Life and Fishes," *Trans. Amer. Fisheries Soc.,* Vol. 62, p. 278-289, 1932.

38. Palmer, C. M., and Tarzwell, C. M., "Algae of Importance in Water Supplies," *Public Works Mag.* (June), 8 pp: 6 plates, 1955.

39. Palmer, C. M., and Poston, H. W., "Algae and Other Interference Organisms in Indiana Water Supplies," *Journ. Amer. Water Works Assoc.,* Vol. 48:10, p. 1335-1345, 1956.

40. Palmer, C. M., "Algae and Other Interference Organisms in New England Water Supplies," *Journ. New England Water Works Assoc.*, Vol. 72:1, p. 27-46, 1958.

41. Palmer, C. M., "Algae and Other Organisms in Waters of the Chesapeake Area," *Journ. Amer. Water Works Assoc.*, Vol. 50:7, p. 938-950, 1958*a*.

42. Patrick, R., "A Proposed Biological Measure of Stream Conditions, Based on a Survey of the Conestoga Basin, Lancaster County, Pennsylvania," *Proc. The Acad. of Nat. Sci.*, Vol. 101, p. 277-341, 1949.

43. Patrick, R., "Biological Measure of Stream Conditions," *Sew. and Indust. Wastes*, Vol. 22:7, p. 926-938, 1950.

44. Prescott, G. W., "Objectionable Algae with Reference to the Killing of Fish and Other Animals," *Hydrobiologia*, Vol. 1:1, p. 1-13, 1948.

45. Purdy, W. C., "Influence of the Discharge of Sewage on Minute Forms of Stream Life," *Sixth Ohio Conf. on Sew. Treat.*, p. 21-34, 1932.

46. Ruchhoft, C. C., and Watkins, J. A., "Bacterial Isolation and Study of the Filamentous Organisms in the Activated Sludge of the Des Plaines River Sewage Treatment Works," *Sew. Works Journ.* Vol. 1:1, p. 52-58, 1928.

47. Sawyer, C. N., "Fertilization of Lakes by Agricultural and Urban Drainage," *Journ. New England Water Works Assoc.*, Vol. 61:2, p. 109-127, 1947.

48. Sawyer, C. N., "Some New Aspects of Phosphates in Relation to Lake Fertilization," *Sew. and Indust. Wastes*, Vol. 24:6, p. 768-776, 1952.

49. Smith, O. R., "Placer Mining Silt and Its Relation to Salmon and Trout on the Pacific Coast," *Trans. Amer. Fisheries Soc.*, Vol. 69, p. 225-230, 1940.

50. Streeter, H. W., and Phelps, E. B., "A Study of the Pollution and Natural Purification of the Ohio River. III. Factors Concerned in the Phenomena of Oxidation and Re-aeration," *Public Health Service Bull.*, No. 146, p. 1-75, 1925.

51. Surber, E. W., and Bartsch, A. F., "Are Chemicals Killing Our Fish and Wildlife?" *Outdoor America*, Vol. 17:5, p. 4-11, 1952.

52. Tarzwell, C. M., and Gaufin, R. R., "Some Important Biological Effects of Pollution Often Disregarded in Stream Surveys," *Proc. of 8th Annual Indust. Waste Conf.*, p. 295-316, 1953.

53. Tsivoglou, E. C.; Harward, E. C.; and Ingram, W. M., "Stream Surveys for Radioactive Waste Control," 2nd Nuclear Engrg. and Sci. Conf., Mar. 11-14, 1957. *The Amer. Soc. of Mech. Engrs.*, p. 1-12, 1957.

54. Van Vliet, R., "Effect of Heated Condenser Discharge Upon Aquatic Life," *The Amer. Soc. of Mech. Engrs.*, paper No. 57-PWR-4, p. 1-10, 1958.

55. Wallen, I. E., "The Direct Effect of Turbidity on Fishes," *Bull. Okla. A. and M. Arts and Sci. Studies, Biol. Ser.*, Vol. 48:2, p. 1-27, 1951.

56. Ward, H. B., "Placer Mining and the Anadromus Fish of the Rogue River," *Science*, Vol. 88, p. 441-443, 1938.

57. Westfall, B. A., "Stream Pollution Hazards of Wood Pulp Mill Effluents," *U. S. Fish and Wildlife Service Fishery Leaflet No. 174*, p. 1-9, 1950.

58. Weston, R. S., and Turner, C. E., "Studies on the Digestion of a Sewage Filter Effluent by a Small and Otherwise Unpolluted Stream," *Mass. Inst. of Tech., San. Research Lab. and Sew. Experiment Stat., Vol. 10*, p. 1-43, 1917.

59. Woker, H., Die Temperaturabhangigkeit der ~~Giftwirkung~~ Giftwirkung von Ammoniak auf Fische. III. Mittlg. der Reihe: Beitrage zur Toxikologie der Fische. *Proc. Intern. Assn. Theor. Appl. Limnol.*, Vol. 10, p. 575-579, 1949.

60. Wurtz, C. B., "Stream Biota and Stream Pollution," *Sew. and Indust. Wastes*, Vol. 27:11, p. 1270-1278, 1955.